

METAL FOILS FOR USE IN PULSED LASER APPLICATIONS*

by

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The metal foils under discussion are 0.002" (50 μ m) and less in thickness. Leaving the mechanical properties for specific applications to the engineers in charge, there are at least three very important metallurgical considerations in the fabrication and use of foils of the thickness mentioned above.

The first is cleanliness. There must be no inclusions in the finished foil, the size of which approximates the thickness of the foil. Such inclusions would be sure to impair the integrity of the foil - clumps of somewhat smaller ones would do the same. In addition long stringers of otherwise acceptable inclusions (0.0001" and less) will, if they occur near the surface, partially separate from the main metal and produce "blisters" and/or "slivers". Long stringers even deep within the foil will impair the fabrication and ductility of the foil though the impairment may not be catastrophic.

The second consideration is grain size. Large grains, the boundaries of which extend from surface to surface, are intolerable in that the grain boundaries of such material are weak and greatly reduce the ductility and toughness of the metal. Thus the grain size for a 0.001" (25 μ m) foil should be about 0.0002" (5 μ m) in diameter, which is an ASTM size 12, or at most 0.00044 (11 μ m) or ASTM size 10. For thinner foil the grain size should be proportionately smaller and may be larger for thicker foil.

A third item of importance is the presence of second and third phases. Preferably foils should be single phase but if any other phases are present they should be discontinuous in nature and if not equally ductile with the first phase should be in small particles so they act as little like inclusions as possible.

A corollary to the grain size problem is that in brazing, if used, care should be taken that excessive grain growth does not occur.

Needless to say, in fabricating these foils good rolling and annealing practices must be used and care and cleanliness must be exercised in the execution of these practices since any defects or problems are magnified - by the thinness of the foils.

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Many if not all of the preceeding axioms have been illustrated in a manner not too reassuring by many of the foils examined so far.

Some of the foils examined metallographically so far are Inconel Inconel 718, Inconel X750, titanium, Ti-6 Al-4V, Ti-3 Al-2.5V, Monel Ni 201 and two stainless steels (301 and 302). No reference will be made to fabricator nor supplier. Remarks will be confined to the worth of the material in regard to the preceeding discussion.

Inconel 600 - Vacuum melted - electro-slag reduced.

57-1-1 shows this material as polished, there are a few inclusion in this metal as shown in the photomicrograph but much less than in sample 53-1 (Inconel 718). 57-1-2 shows the microstructure - somewhat cold worked after recrystallization - ASTM grain size somewhat larger than #8, which is not good.

Inconel 718 - Vacuum melted. 53-3-1 and 43-3-2 show typical inclusions found in 718. 53-3-3 shows that it has been annealed and pinch rolled. ASTM grain size about 10.

This material was then given a heat treatment similar to the brazing and aging, about 1875°F for 30 minutes with 2 minutes above 1925°F. 53-1-1 and 53-1-3 show typical large inclusions which upon microprobe analysis were found to be carbides. 53-1-3 and 53-1-2 were etched and show large grains (ASTM 8 and larger) which extend from surface to surface and will not have good mechanical properties. The grains probably would have been even larger had not the thickness of the foil prevented growth.

It is obvious that the braze cycle has caused appreciable grain growth.

Inconel 718 - another sample (vacuum melted).

Plates 55-1-1 and 55-1-2 show the microstructure of these materials. 55-1-1 is unetched and shows somewhat excessive inclusions. 55-1-2 is etched and shows an almost satisfactory grain size (i.e., about ASTM 11). It would be better if the size were about 11 or, preferably, 12. No cold work is evident.

Inconel X750 (vacuum melted, non metallics added).

There was a sliver on the surface of this piece - which is reported to happen only on Inconel 750. 57-2-1, 2-2 and 2-3 show sections through the sliver and reveal what appears to be a precipitate as a probable cause of the sliver. 57-2-4 shows a typical precipitate stringer found in abundance scattered throughout the metal. When such a stringer occurs near the surface it could very easily promote a sliver such as this one. 57-2-5 shows a fully annealed metal of about #8 grain size. The inclusions probably are carbides, being rather angular, the small ones being broken up from the big ones and strung out through the metal.

Titanium - "Pure"

55-2-1 shows a section through the foil from which two diaphragms were cut, grain size #10 and reasonably clean, no cold work. 55-4-1 was a used but unruptured diaphragm and appeared browned in some areas where the electron beam had struck it. The microstructures are from two areas, the two to the left (outside the electron beam) were relatively unchanged microstructurally and the one to the right, which came from a browned area, was markedly changed in that the grain size had increased and had undergone a more rapid cooling than the original, forming acicular α phase.

55-3-1 and 55-3-2 came from a ruptured diaphragm, parts of which blued (around the burst area) possibly by oxidation from the heat and residual oxygen in the system.

In 55-3-1 the left hand piece was outside the electron beam area and the one on the right is from a browned area. In 55-3-2 both pieces were from the blued area and the thin surface layer is just beneath the blued surface. Ion probe analysis revealed the presence of N in the blued surface which promotes the formation of β phase titanium, the remainder being acicular α .

Ti-6Al-4V

53-2-1 shows cold rolled structure in which the grains have been elongated and the β is elongated stringers. The suggestion has been made that the dark lines are "phase separations." This may be true to some extent but 53-2-2 at 2000X does not show it. Very few inclusions were found. This material was then annealed at 1200K (1700°F) for 20 minutes then 1215K (1725°F) two minutes and furnace cooled. 53-4-2 shows an annealed structure of α titanium a complete β network at the grain boundaries.

Ti-3Al-2.5V

There were two samples of this. The first is shown in 57-3-1. There is some β phase present but is insufficient to make a complete network at the grain boundaries and therefore should fabricate fairly well. The grain size is good (close to ASTM 12). Inclusions are good.

The second piece looked much the same with perhaps less β phase. There were few inclusions.

Monel 400

This is pretty good material as far as inclusions is concerned but has rather large grain size (57-5-1 and 57-5-2) about ASTM #8.

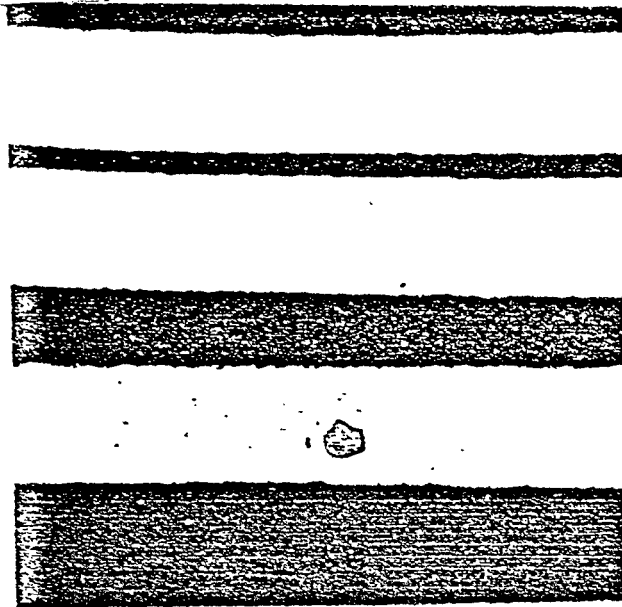
Ni 201

Clean as to inclusions, cold worked structure (57-6-1).

Stainless Steel - air melted.

53-5-1 shows inclusions in the SS 301 and 53-5-2 shows the structure some cold work. Type 302 is shown in 53-6-1 and 53-6-5.

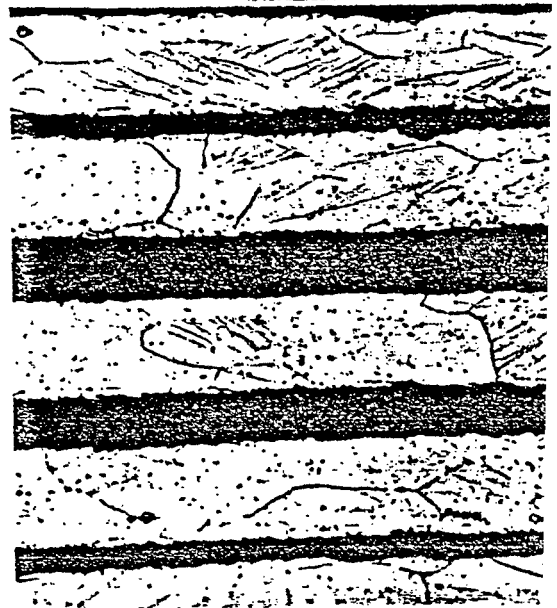
Another stainless steel foil was rather dirty as to inclusions and coarse grain for the foil thickness (0.0005"), plate 55-5-2.



57-1-1

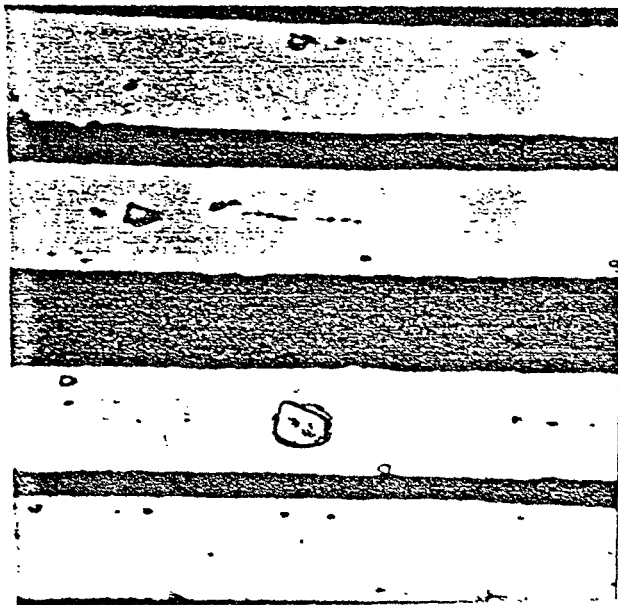
As polished - Inc, 600
a few inclusions

500X



57-1-2

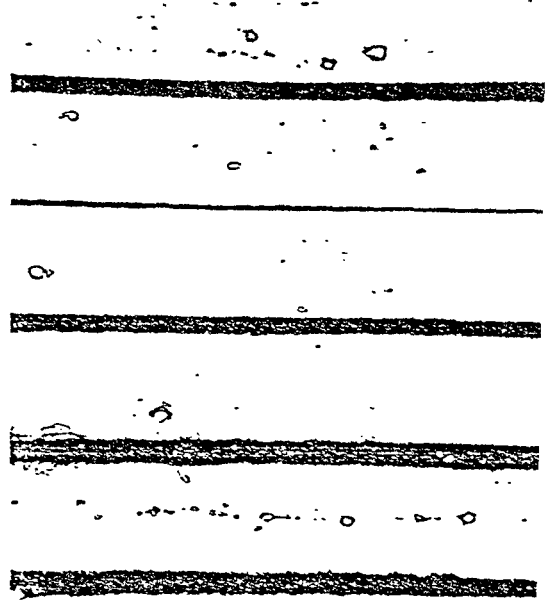
Etched - Inc, 600
some cold work



53-3-1

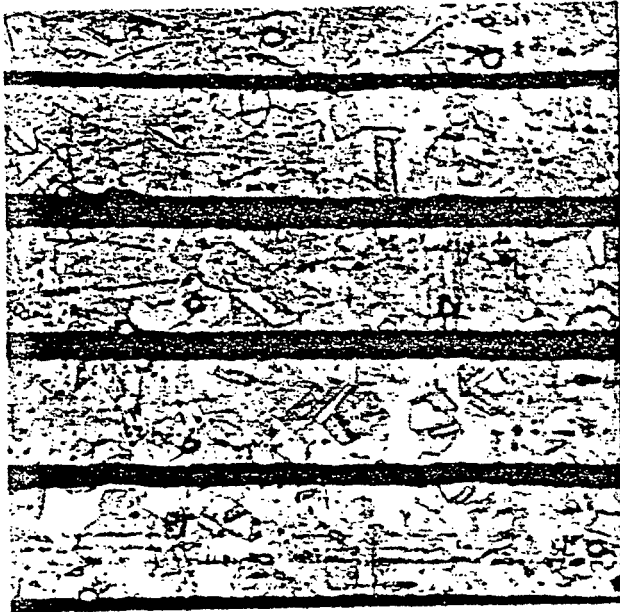
Inc, 718 - as received
large carbide inclusions

500X



53-3-2

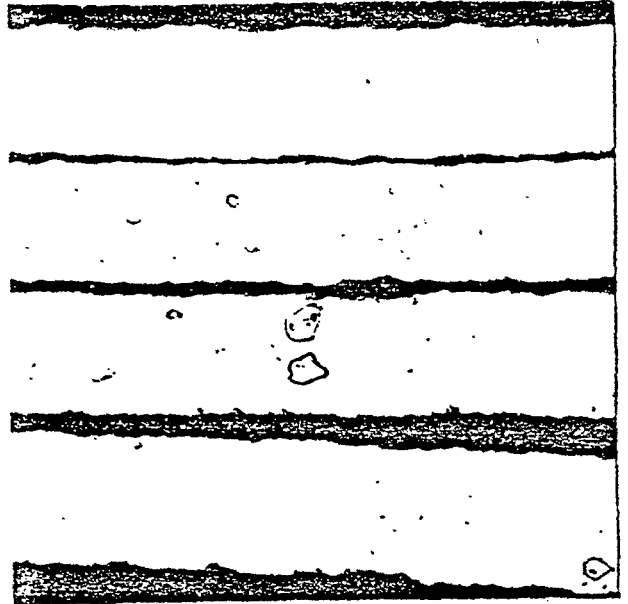
Inc, 718 - as received
stringers of inclusions



53-3-3

500X

Inc. 718 - as received
annealed and "pinched"



53-1-1

500X

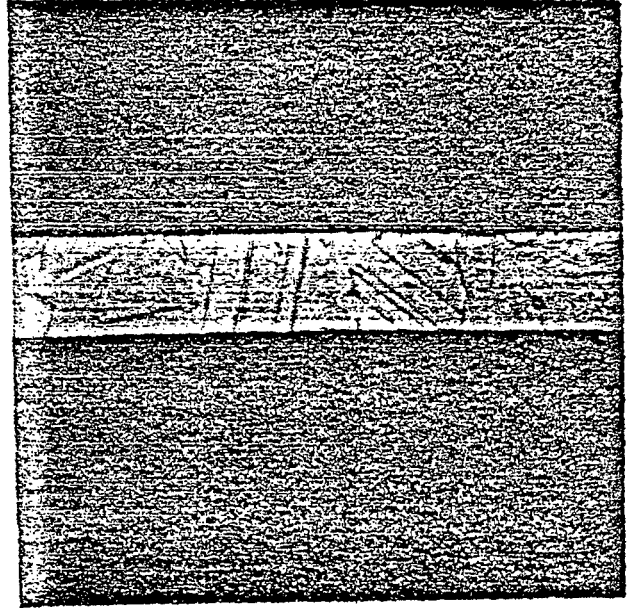
Inc. 718 - as polished
typical inclusions



53-1-3

500X

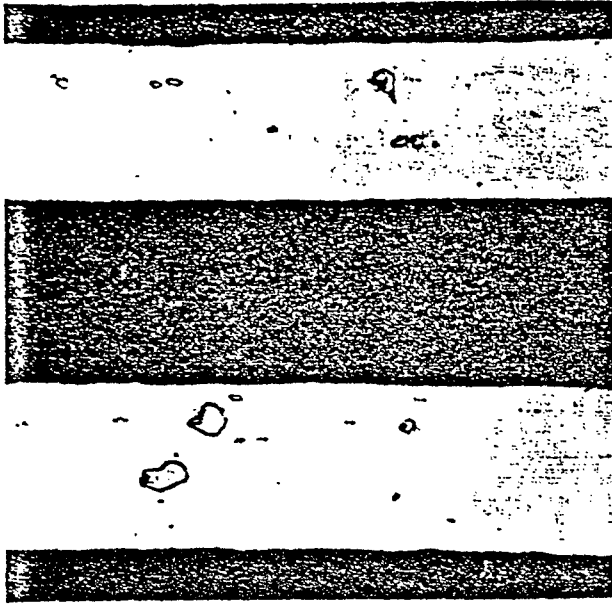
Inc. 718 - etched
grains ASTM 8



53-1-2

500X

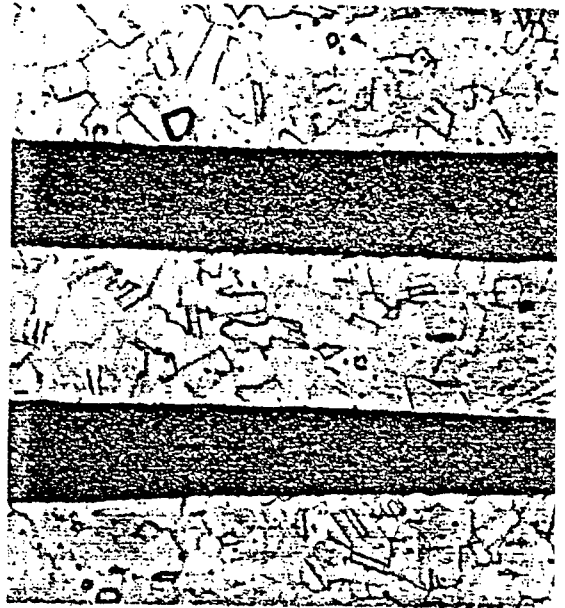
Inc. 718 - etched
grains > ASTM-8



55-1-1

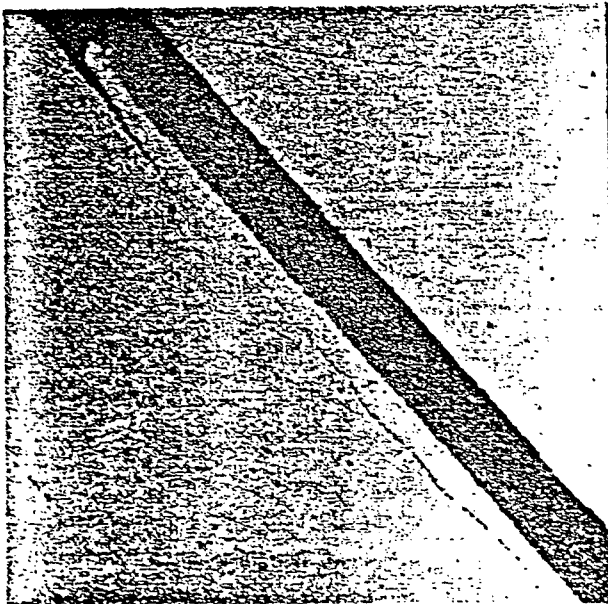
Inc. 718 - as polished
excessive inclusions

500X



55-1-2

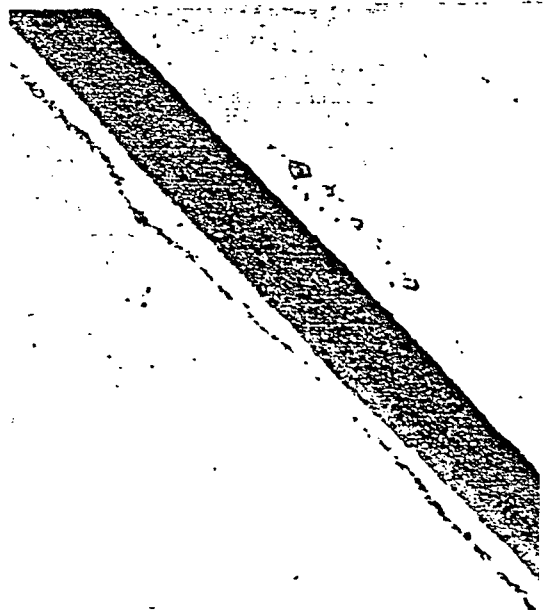
Inc. 718 - etched
ASTM grains #9



57-2-1

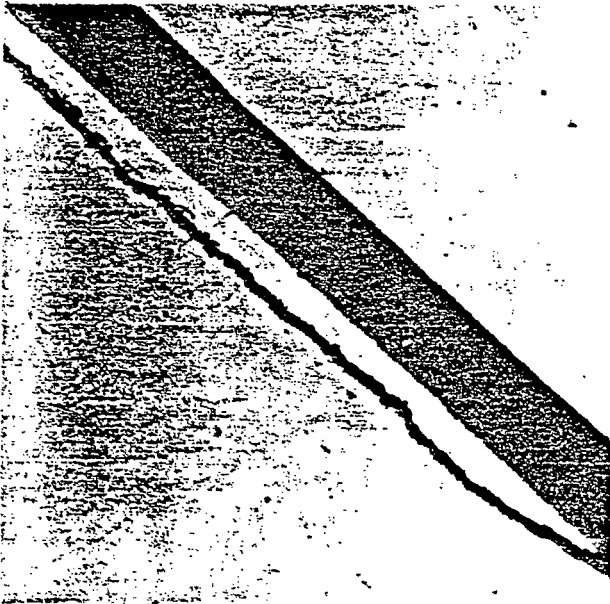
Inc. X750 - as polished
one end of sliver

500X



57-2-2

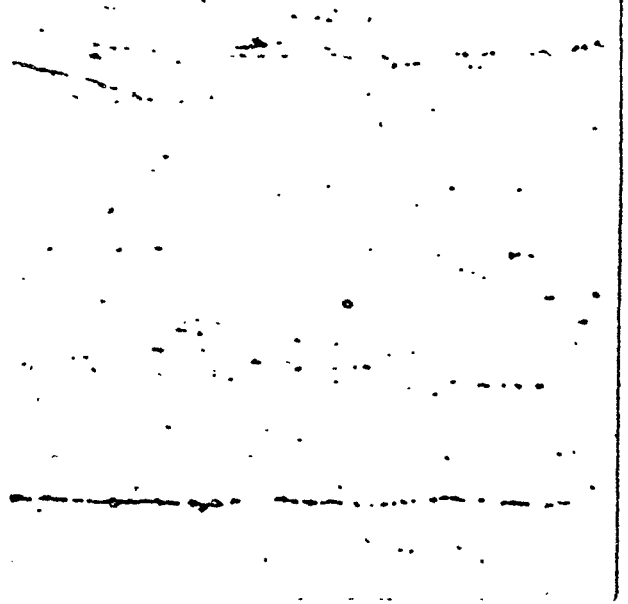
Inc. X750 - polished
center of sliver



57-2-3

500X

Inc, X750 - polished
end of sliver



57-2-4

500X

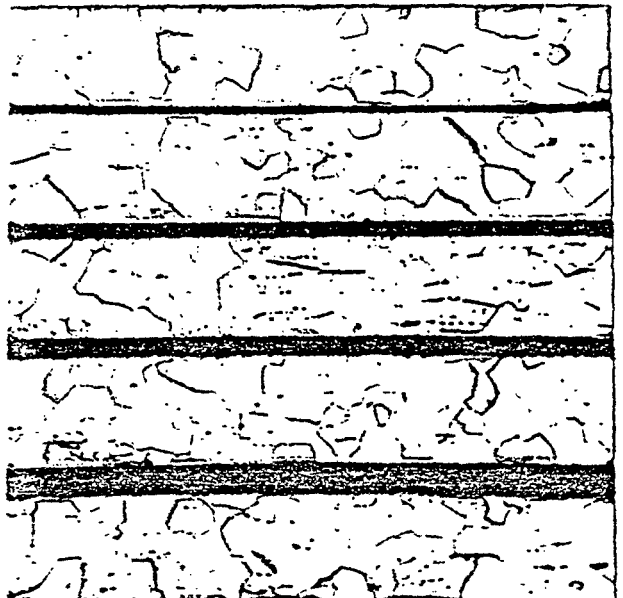
Inc, X750
stringer of inclusions



57-2-5

500X

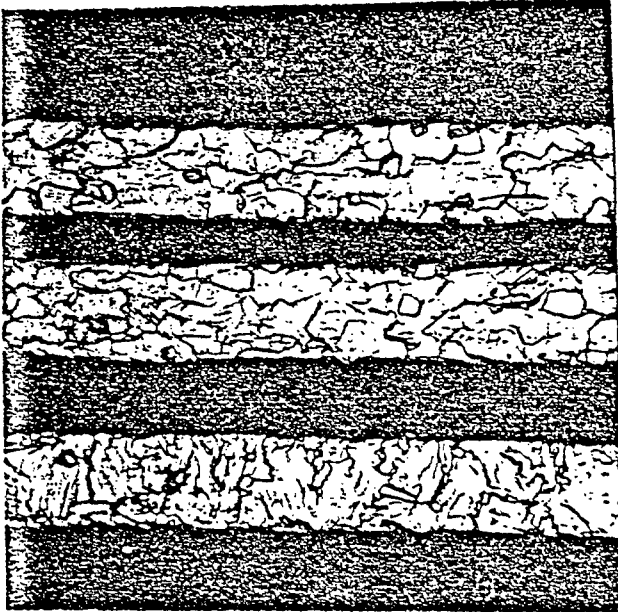
Inc, X750 - etched
annealed structure, angular
dark spots are inclusions



55-2-1

500X

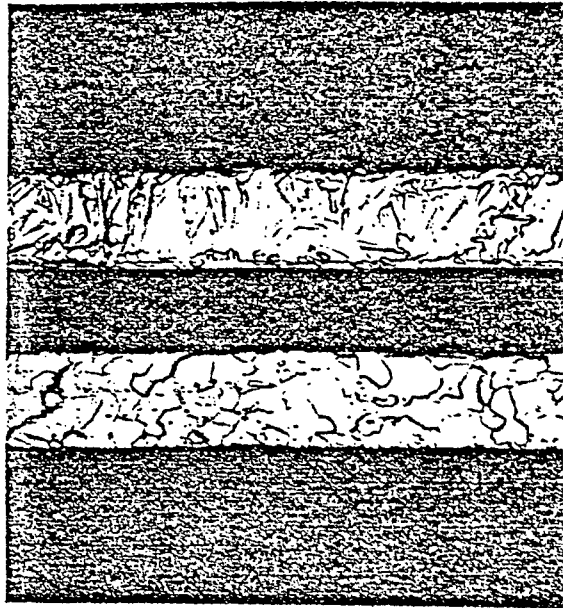
Titanium - etched
grain size about ASTM 10



55-4-1

500X

Titanium - etched
two areas to left relatively unchanged
right area has been heated such as to
induce grain growth - cooled rapidly



55-3-1

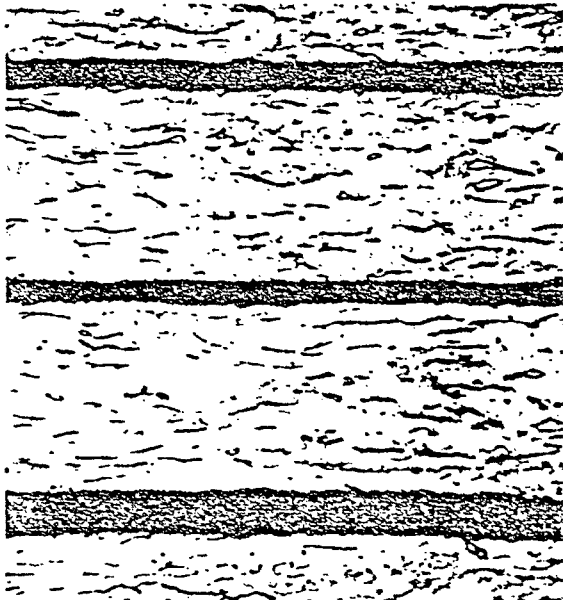
Titanium - etched
left one unchanged
right one - grain growth and thin
layer of β



55-3-2

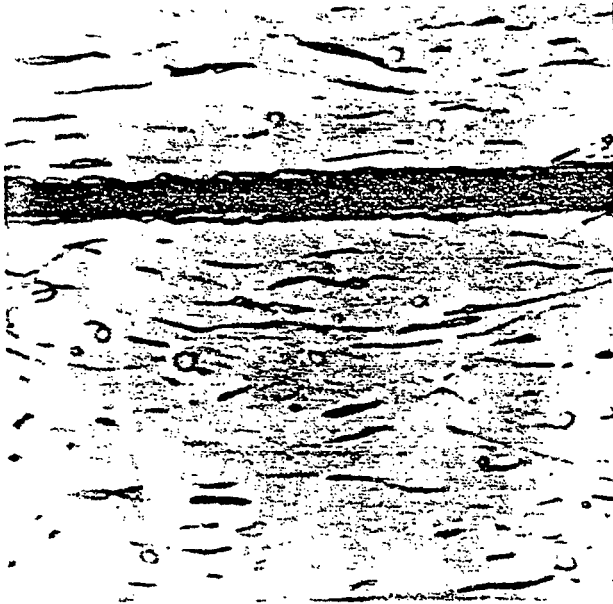
500X

Titanium - etched
layers probably β , stabilized by N



53-2-1

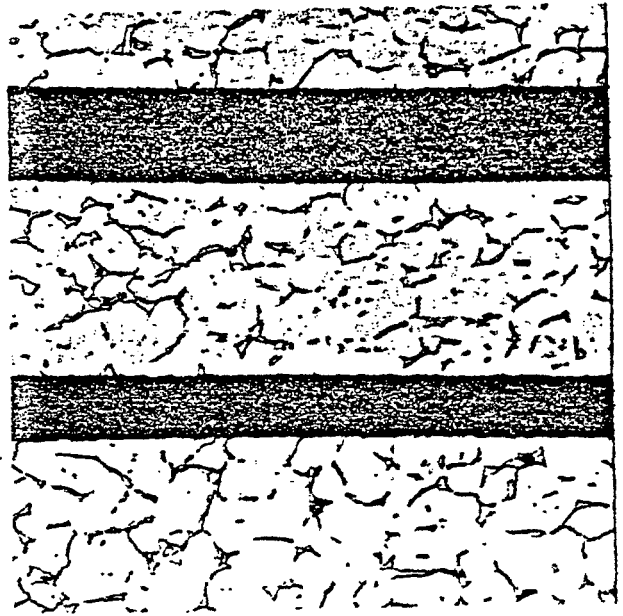
Ti-6-4 - as rolled
 β appears as dark stringers



53-2-2

2000X

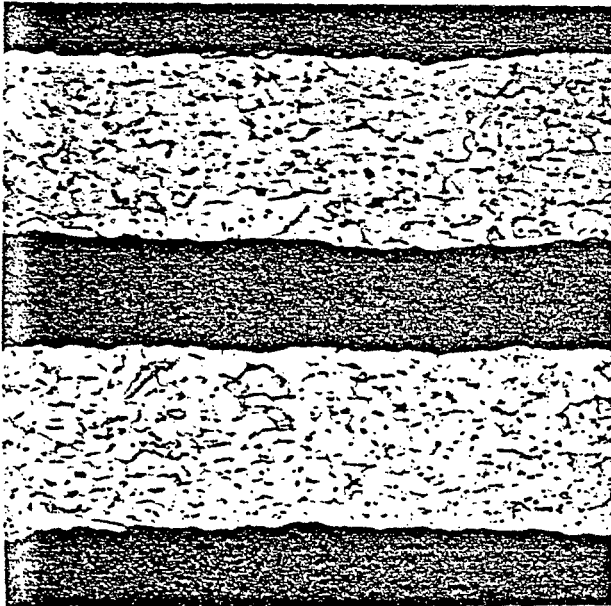
Ti-6-4 - as rolled
elongated grains of α width with
stringers of β



53-4-2

1000X

Ti-6-4 - etched
light grains are α and dark
areas are β titanium



57-3-1

500X

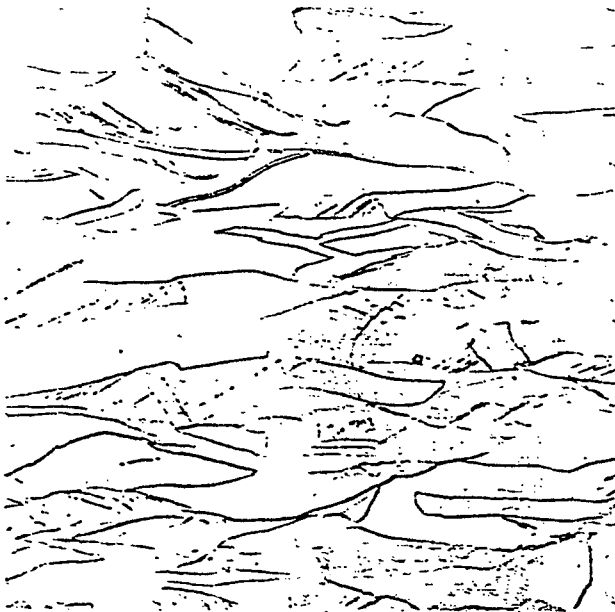
Ti-3-2.5 - etched
small amount of β but not
complete network



57-5-1

500X

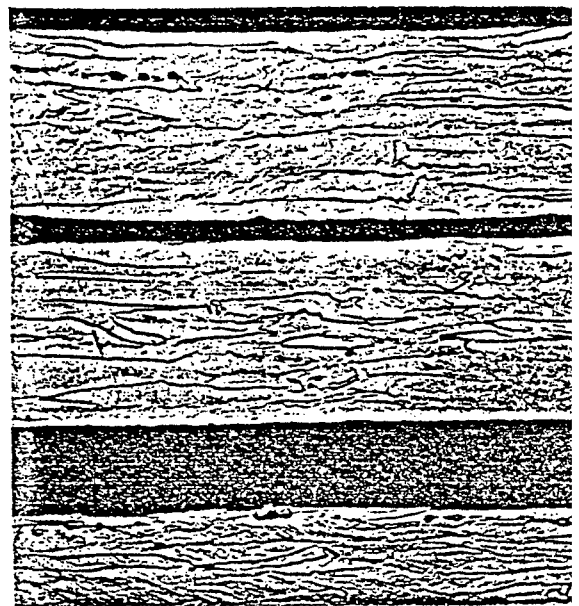
Monel 400 - polished
stringers of inclusions



57-5-2

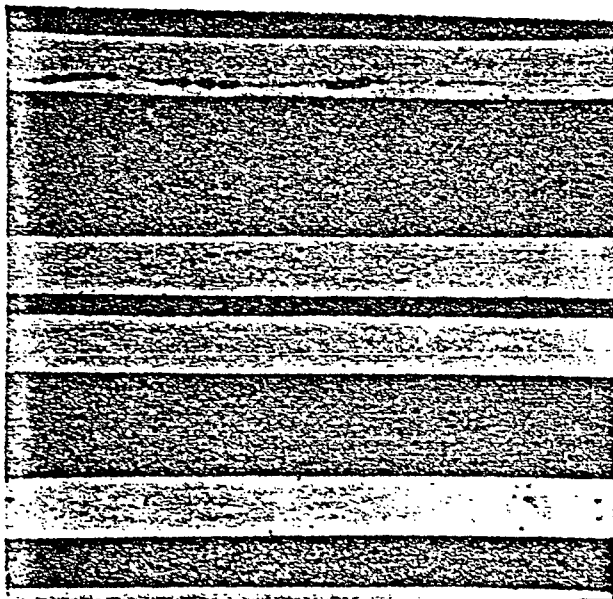
500X

Monel 400 - etched
cold rolled



57-6-1

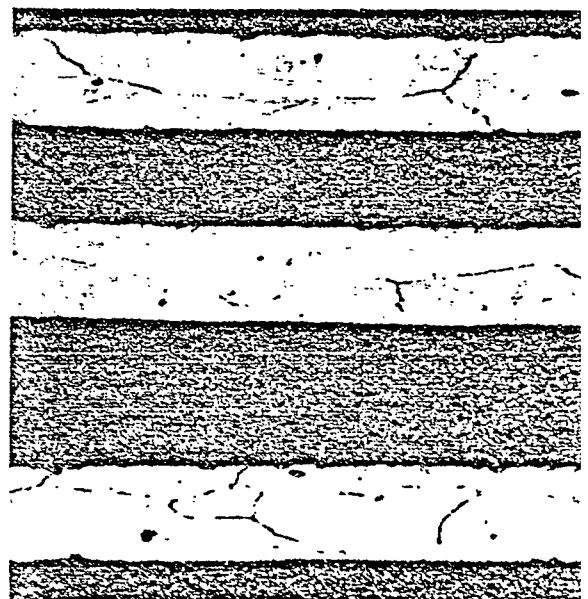
Ni-201 - etched
cold rolled



53-5-1

500X

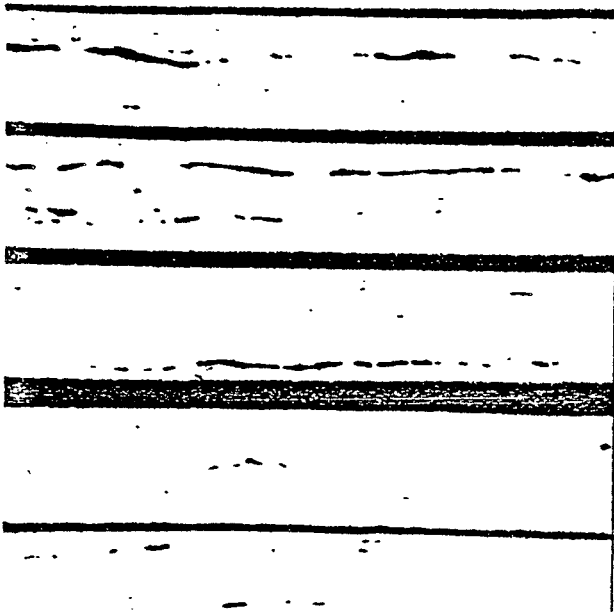
SS 301 - polished
inclusions



53-5-2

SS 301 - etched
structure

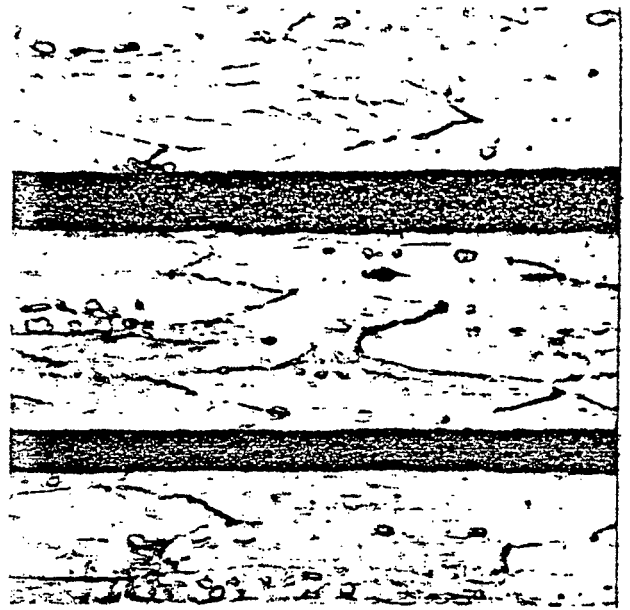
10



53-6-1

500X

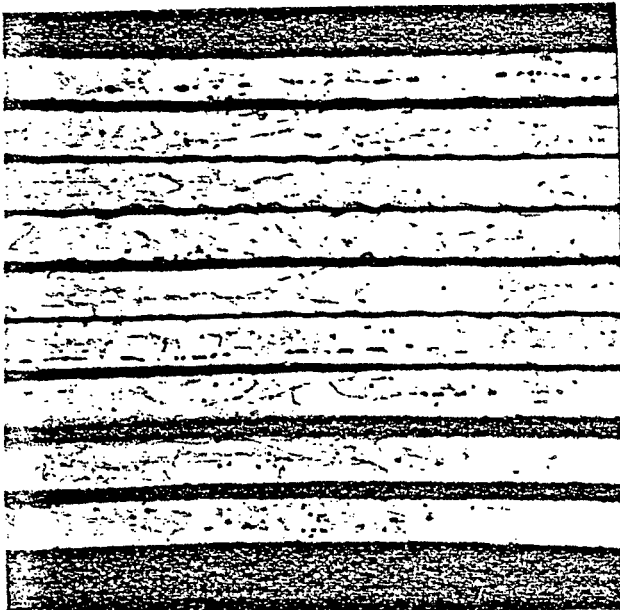
SS 302 - polished
inclusions



53-6-5

500X

SS 302 - etched
cold worked



55-5-2

500X

SS 302 - etched
annealed

N-Ti

990

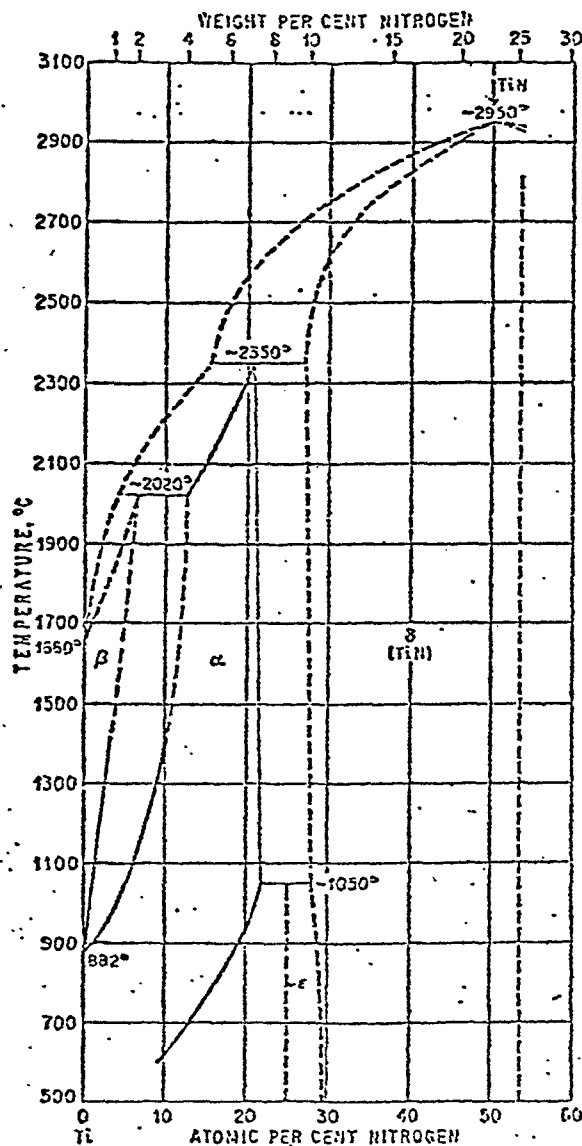


Fig. 545. N-Ti

The diffusion of nitrogen in Ti has been studied by [36]. Specimens reacted above and at 950°C showed two ($\delta + \alpha$) and three ($\delta + \epsilon + \alpha$) surface layers, respectively. However, a triple layer was also observed in specimens reacted at 850°C below the transformation temperature of Ti. [36] stated, therefore, that "the available data on the Ti-N equilibrium diagram [Fig. 545] below the transformation temperature are insufficient to permit complete interpretation of the surface-layer structures present."